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DETERMINATION OF THE GRAVITATIONAL FIELD
OF THE MOON BY THE MOTION OF
THE AMS LUNA-10

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The motion of LUNA-10 is studied in the noncentral gravitational field of the Moon, taking into account the gravitational influence of the Earth, Sun and planets.

Eleven coefficients of expansion of Moon's gravitational potential are obtained from trajectory measurements.

Pear-like shape of the surface with elongation on the far side of the Moon is evident. It is basically formed under the influence of the terms in potential's expansion containing the cubic harmonic P_3^1 (with the coefficient c_{31}) and the zonal harmonic P_2^0 .

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If the gravitational field of the Moon were central, while the influence of the outer bodies is absent, the motion of the satellite would take place along an unperturbed orbit (Keplerian ellipse), of which the shape and dimensions would remain invariable in absolute space. The noncentrality of the Moon's gravitational field and the action of outer bodies, of which the principal ones are the Earth and the Sun, induce perturbations in the motion of the satellite. Under the action of the latter the satellite orbit is bound to evolve with time.

The perturbing action of the Earth and the Sun on the motion of Moon's satellite is well known. The greatest interest is offered by orbit evolution arising on account of an unknown noncentrality of the gravitational field of the Moon. The knowledge of this evolution allows to determine its parameters.

Author

* OPREDELENIYE POLYA TYAGOTENIYA LUNY PO DVIZHENIYU ISL "LUNA-10"

Trajectory measurements of satellite motion, conducted in the entire period of its existence (from 3 April to 30 May 1966) were used to ascertain the evolution of LUNA-10 orbit. They were subject to statistical processing with the view of joint determination of parameters of Moon's gravitational field and of the elements of its orbit. Laid at the basis of the method of measurement processing was the analytical theory of motion of a Moon's satellite that would allow to encompass the entire two-month measuring interval of satellite motion.

The description of selenocentric motion of the satellite and of the motion of the Moon around its proper mass center was performed in the Descartes rectangular selenocentric system of coordinates XYZ. The plane XY of this system coincides with the plane of the mean equator of the Moon, and the plane XZ overlaps with the plane of its zero meridian of the t_0 epoch. The directions of the axial system are fixed relative to stars. The axis X of the system is directed toward the Earth, the axis Z — to the northern pole of the Moon and the axis Y completes the right-hand system. The following elements of satellite orbit are used for the description of its motion: major semiaxis a , eccentricity e , inclination i , longitude of the ascending node Ω , angular distance from pericenter to the node ω , time of node passage T_Ω (The counting of the angular orbital elements i , Ω , ω is made from the Moon's mean equatorial plane and its zero meridian of t_0 epoch by the method admitted in celestial mechanics). It is assumed that the rotation of the Moon around its proper mass center takes place according to Cassini laws, i. e., uniformly around the fixed axis OZ of the introduced system of coordinates. The motion of the mass center of the Moon (origin of the system of coordinates) in the geoequatorial system of coordinates with the mean equinox of the epoch 1960.0 is given by the Braun theory.

The noncentrality of the gravitational field of the Moon is the essential fact determining the evolution of the orbit of LUNA-10. The perturbations of satellite orbit arising on account of the noncentrality of the gravitational field of the Moon are particularly clearly manifest in the evolution of the longitude Ω of the ascending node of the satellite and of the angular distance ω from periselenion to the node. This evolution of the elements Ω , ω during the time of its existence is represented in Fig.1 as a function of the number of satellite convolutions. The evolution of parameters Ω , ω contains a visible secular offset leading to regression of both parameters. A noticeable periodical perturbation is superimposed on the secular offset of parameter ω . For 460 satellite convolutions the perturbations of parameters Ω , ω , conditioned by the noncentrality of the gravitational field of the Moon attained the values $\Delta\Omega = -7.7^\circ$; $\Delta\omega = -11.8^\circ$. The perturbation of satellite orbit inclination i and of its eccentricity e bear fundamentally a periodical character and have an amplitude $\Delta i \approx 0.15^\circ$; $\Delta e \approx 0.003$.

The satellite orbit perturbation on account of field noncentrality leads to perturbations of its coordinates, constituting for a single satellite convolution a value $|\Delta r| \approx 0.75$ km.

The above comparative estimates show that for the orbit of LUNA-10 the perturbations on account of Moon's gravitational field noncentrality exceed by a factor of 5 - 6 the perturbations caused by the gravitational influence of the Earth and the Sun. The planetary perturbations of satellite motion are small over the considered time interval and this is why they were not considered.

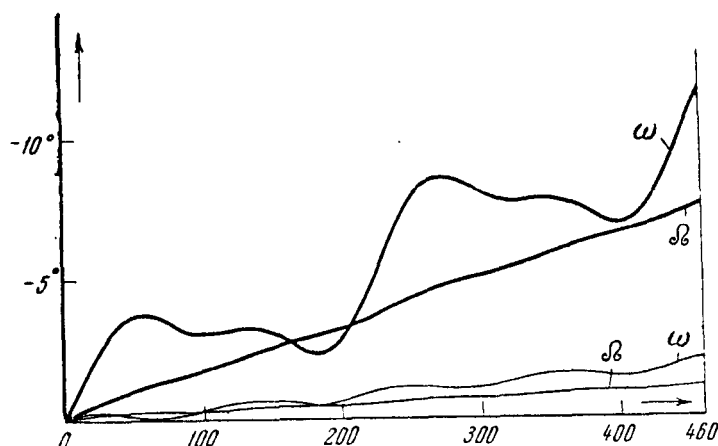


Fig.1. Perturbations in the longitude Ω of the ascending node and in the angular distance ω from the pericenter to orbit node. Heavy lines refer to the noncentrality of Moon's gravitational field, the thin lines point to perturbations on account of gravitational influence of the Earth and the Sun

The processing of trajectory measurements, containing their unique dynamic tie over the flight interval of LUNA-10 for two lunar months allowed to determine the quantitative characteristics of the noncentrality of Moon's gravitational field.

The expression for the gravitational potential U of the Moon is accepted in the form of expansion in series by spherical functions

$$U(r, \psi, \lambda) = \frac{\mu}{r} \left\{ 1 + \sum_{n=2}^{\infty} \sum_{m=0}^n \left(\frac{R}{r} \right)^n [c_{nm} \cos m\lambda + d_{nm} \sin m\lambda] P_n^m(\sin \psi) \right\},$$

where μ is the mass of the Moon, R is its mean radius; r, ψ, λ are the spherical coordinates of the point: r is the polar radius, ψ is the latitude counted from the mean equator of the Moon, λ is the longitude counted from the zero meridian of the epoch t_0 ; $P_n^m(\sin \psi)$ are the connected Legendre functions. We utilized for the determined parameters of Moon's gravitational field the coefficients c_{nm}, d_{nm} of this expansion.

As a result of this processing we obtained the numerical values for eleven expansion coefficients of the gravitational potential of the Moon. Together with their maximum possible errors these values are presented below:

$$c_{20} = (-0,206 \pm 0,022) \cdot 10^{-3},$$

$$c_{21} = (0,157 \pm 0,059) \cdot 10^{-4},$$

$$d_{21} = (0,361 \pm 0,358) \cdot 10^{-5},$$

$$c_{22} = (0,140 \pm 0,012) \cdot 10^{-4},$$

$$d_{22} = (-0,139 \pm 0,145) \cdot 10^{-5},$$

$$c_{30} = (-0,363 \pm 0,099) \cdot 10^{-4},$$

$$c_{31} = (-0,568 \pm 0,026) \cdot 10^{-4},$$

$$d_{31} = (-0,178 \pm 0,032) \cdot 10^{-4},$$

$$c_{32} = (0,118 \pm 0,047) \cdot 10^{-4},$$

$$d_{32} = (-0,702 \pm 4,595) \cdot 10^{-6},$$

$$c_{40} = (0,333 \pm 0,270) \cdot 10^{-4}.$$

There is a substantial correlation between the errors in the determination of parameters c_{20} and c_{40} . The correlation factor is $k = -0,99$. The mutual correlation between the errors of the remaining determined parameters does not exceed 0.4.

The above numerical values of parameters c_{20} and c_{22} agree well with their known values obtained by libration measurements [1].

The nonzero value of the coefficients c_{nm} with odd index m and of coefficients d_{nm} with an even index m suggests that the gravitational field on the visible and the far sides of the Moon is asymmetrical.

For the illustration of a specific gravitational potential of Moon we considered the level surface passing through the point with spherical coordinates $r = 1738$ km, $\psi = 0$ and $\lambda = 0$.

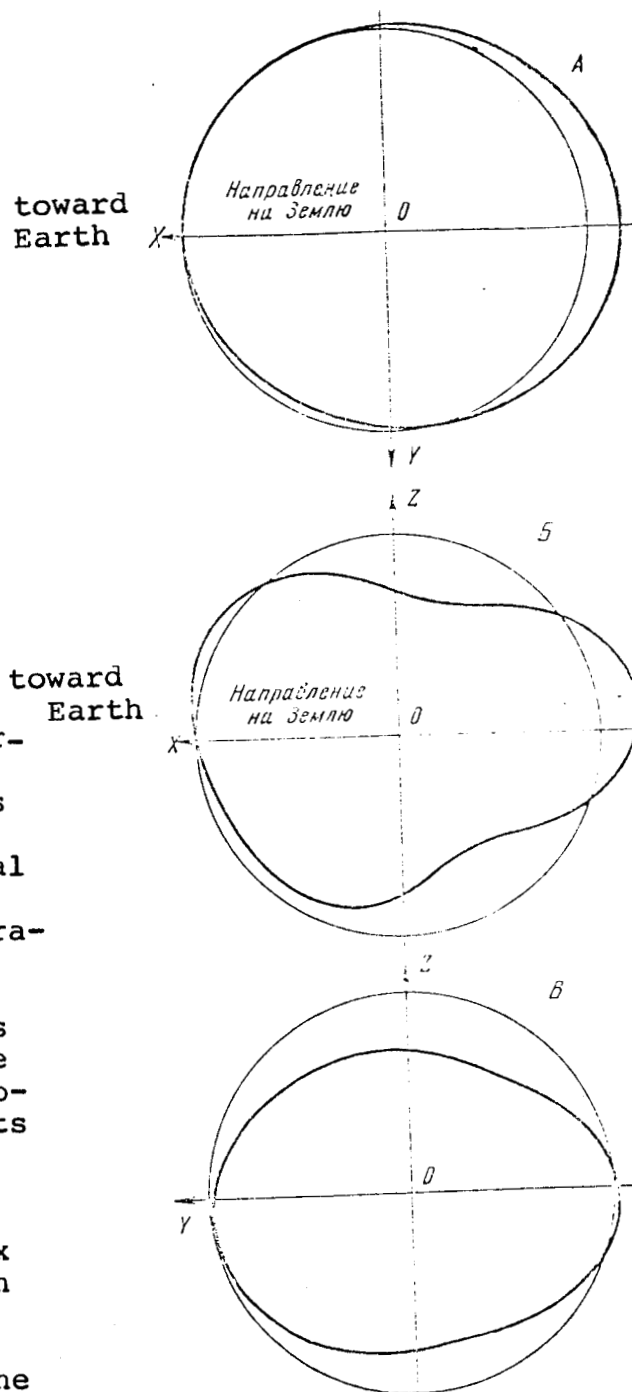


Fig.2. Cross-sections of the level surface of the Moon's gravitational potential (radial deflections from the circumference $\times 1000$ times). A) Equatorial, B) meridional ($\lambda = 0$), B) meridional ($\lambda = 90^\circ$)

The shape of the potential surface is clearly seen as pear-like with elongation on the far side of the Moon. This pear-like shape is formed mainly under the influence of the terms in the potential expansion containing the cubic harmonic P_3^1 with the coefficient c_{31} and the zonal harmonic P_2^0 .

The above results are preliminary. The furthest processing of trajectory measurements on LUNA-10 and the analysis of subsequent AMS will permit the refining of the obtained parameters and complement them further, and it will be also possible to refine the motion of its center of masses.

***** T H E E N D *****

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